Attracting Students to Semiconductors through Interactive Learning Experiences – a Tutorial

Gerhard Klimeck*
Purdue University, Network for Computational Nanotechnology, West Lafayette, IN 47907, USA
*e-mail: gekco@purdue.edu

Semiconductor supply chain and security concerns have sparked a global race to re-shore semiconductor manufacturing. Projections indicate a shortage of 42,000 engineers in the U.S. who can architect, design, manufacture, and test chips [1]. These engineering functions are encapsulated in a complex modeling and simulation tool chain that extends from atoms to systems. The high barrier of entry into the field is evident, as we are not attracting and retaining enough students and we never truly use any of these tool chains for teaching. Many groups propose refining lectures and textbooks and hosting them on the web. However, I believe this approach is not much better than the VCR-taped lectures I experienced 30+ years ago. Instead, I advocate for interactive, immersive, project-driven learning to truly attract students into the field. In this tutorial, I will present several aspects of this approach.

nanoHUB has made device and materials modeling more accessible by offering Apps powered by advanced simulation engines in the nanoHUB cloud. Over 84,573 students have used these tools in 4,247 courses at 404 institutions. Overall we have identified clustered user behavior in 141,877 users at 1,448 institutions. The nanoHUB team initially developed user behavior analytics to demonstrate to NSF that scientific Apps in the cloud can be effectively used in education. This capability now guides educational design and provides feedback to faculty members.

A typical course in semiconductor devices follows a sequence that includes crystals, quantum mechanics, band structure, semi-classical carrier statistics, 1D drift diffusion models, PN junctions, bipolar junction transistors, MOS capacitors, and MOSFETs. nanoHUB offers numerous Apps and tools for these concepts, leading faculty to request recommendations. In response, Dragica Vasileska (ASU), student Xufeng Wang and I developed ABACUS [3], which consolidates these tools. As of January 2025, over 74,500 users from more than 1,690 institutions have utilized ABACUS and its constituent Apps. This tutorial will demonstrate several of the ABACUS and related tools.

Beyond ACACUS I also plan to share how I restructured the graduate level Semiconductor Device Fundamentals course in Electrical and Computer Engineering at Purdue University. I believe that this can be translated or adopted towards undergraduate students and even be introduced into first year engineering.

The course restructuring has been influenced by my personal learning experiences and observations of my students. I categorize students into two groups: the mathematically driven learners (which includes my younger self) and the hands-on, practical learners (reflecting my experience as a researcher and developer). As a mathematically inclined student, I could solve all the analytical problems presented to me. However, I realized that I lacked a "physical feeling" for concepts like the Fermi level or a degenerate semiconductor.

On the other hand, the practical learners, especially those in my online classes who are often full-time working engineers, struggle with math and physics. For them, traditional derivations and explanations completely fail to convey physical meaning. To address this, I replaced traditional exams with hands-on projects that provide real-world design experiences and enhance device understanding. There are 2 projects involving Quantum Dot Design and nanowire transistors. Both types of learners finish the course with a much better grasp of the subject matter. I hope to inspire others to adopt similar changes in their courses.

I would like to thank nanoHUB Technical Director Dr. Daniel Mejia for many discussions and amazing tool and analytics developments.

[1] www.semiconductors.org/chipping-in-sia-jobs-report/
[2] N K Madhavan, M Zentner, G Klimeck, "Learning and research in the cloud", *Nature Nano* 8, 786– (2013)
[3] X Wang, et al (2021), "ABACUS …," https:// nanoHUB .org/resources/abacus. (DOI: 10.21981/YYFZ-7868).
[4] Usage data: https://nanohub.org/dashboards/abacus

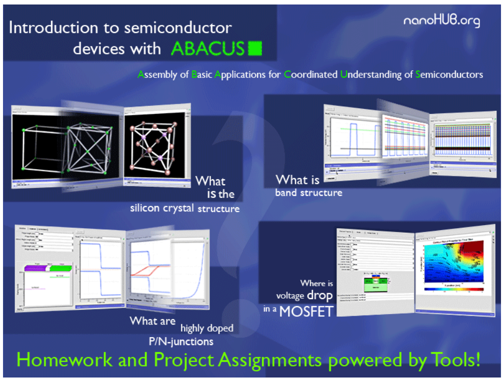

Fig. **1**. ABACUS splash screen highlighting typical semiconductor course topics from crystals to MOSFETS.

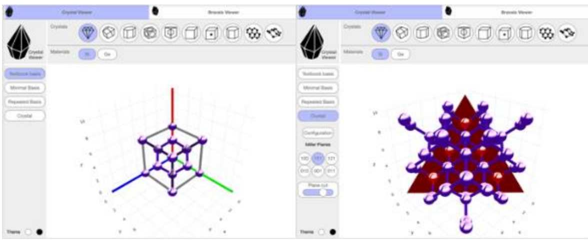

Fig. 2. Crystal viewer screen shots. (left) textbook unit cell that can be rotated. (right) crystal chunk with a Miller plane.

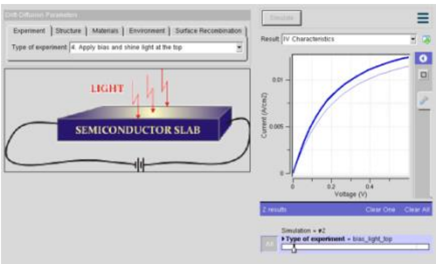

Fig. 3. Drift Diffusion Lab. Users can explore how illumination of a semiconductor increases the current and separates the hole and electron distribution across the device.

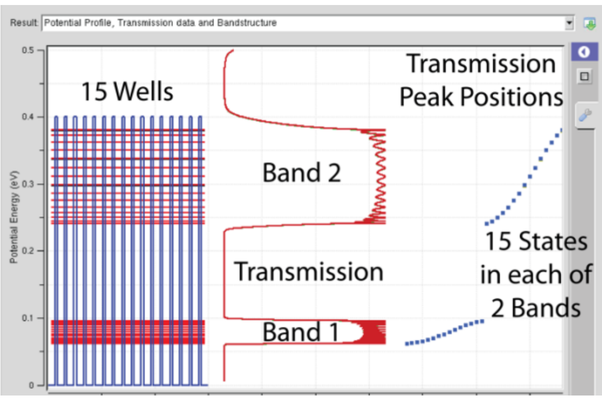

Fig. 4. How many atoms does it take to get bandstructure? Users can vary the number of barriers/wells and observe band formation visualized by transmission through barriers. The peak positions clearly identify the bands. Electrical engineers can relate to a band-pass filter.

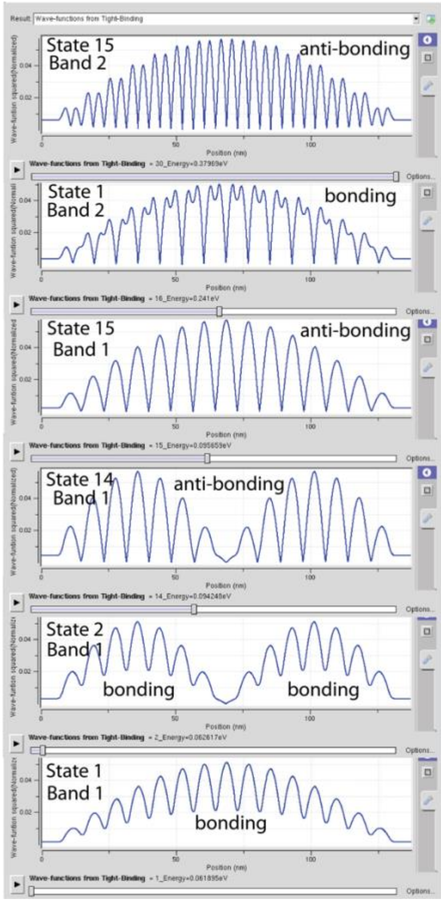

Fig. 5. Wavefunctions of the states in Figure 4 in a system of 16 barriers and 15 wells. The fist 15 states form a band. State 1 is the ground state of a particle in a box consistent of 15 "atoms". State 2 has two lobes. The states at the top of the band (typical valence bands) have the same envelopes as the bottom states but are anti-bonding. The concept of Bloch states emerges naturally.

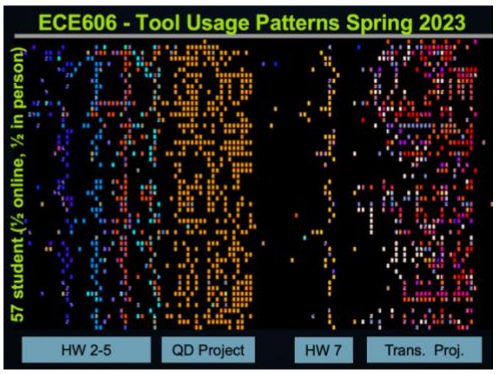

Fig. 6. Tool usage pattern of Purdue's ECE606 class in the spring of 2023. Dots indicate tool use on a specific day (horizontal axis) by the 57 class members who are vertically stacked. Dot colors designate a tool. The Quantum Dot (QD) Project spans several weeks. The nanowire transistor design project involves several different tools ranging from classical transport to fill atomistic quantum transport.